INFINEON

Infineon EPS User Manual

Permanent Magnet Synchronous Motor EPS User Manual

2013

Permanent magnet synchronous motor EPS system scheme based on Infineon devices, with high safety, high efficiency, high reliability, low cost advantages, system with power control, the damping control, active return-to-center control, fault diagnosis, etc.

Contents

1 Introduction

Infineon is the world's largest automotive semiconductor companies in the automotive semiconductor dominant position, such as power components, communication, power supply, microcontroller, sensors, etc. Because the Infineon semiconductor in auto field has high safety, efficiency advantages of low cost. The automotive power steering system based on Infineon devices is also a lot of EPS enterprise's first choice.

Key components of the permanent magnet synchronous motor based on Infineon EPS solution, this system is string type EPS, the working process of the whole system can be convenient external display monitor state, including current and steering wheel Angle, torque, etc. At the same time, it can be adjusted system simulation speed and simulated booster effect and back to the positive in different car speed through this interface. System has the function of power control and damping control, active return-to-center control function, self-diagnosis and communication function.

System control chip microcontroller using Infineon XC2336B and XC836MT, XC2336B do host microcontroller to achieve the core of the electric power steering control system to complete the signal acquisition and processing, communication, power control, damping control, active return, fault diagnosis, XC836MT for the secondary monitor microcontroller, mainly through the communication means to communicate with the main microcontroller XC2336B, real-time monitoring host microcontroller XC2336B, in the main microcontroller XC2336B recovery in case of failure of the main microcontroller XC2336B, if unrecoverable circumstances can shut down the entire system to ensure system security.

Power control, the system uses Infineon's MOSFET IPB120N04S402 and MOSFET pre-driver TLE7189QK. IPB120N04S402 achieve sustainable working current 120A, whose voltage is 40V, with on-resistance as small as 1.8mΩ, so the system's heat is very small. Since TLE7189QK has three op-amps to ground, so you can easily realize the way through the current sampling resistor, and can greatly save system cost.

System characteristics of CAN, LIN, UART communication function. High speed CAN communication Transceiver with Infineon TLE6250G, LIN communication uses Infineon TLE6258-2G.

System power uses Infineon's TLE42764D V50 and TLE4250-2G. TLE42764D V50 has 400mA output current capability, power supply for the system main and auxiliary microcontroller, TLE7189QK, CAN communication, LIN communication, and UART communications. Meanwhile, the chip has enable control, the control port can be controlled by the ignition signal to Control the operation of the controller of work to stop to ensure that non-working state in the automotive EPS with very low power consumption. TLE4250-2G follower for the power, torque sensor designed for power, to prevent short circuit caused by an external sensor system is not controllable major security risk.

Devices based on Infineon permanent magnet synchronous motors EPS scheme (Figure 1.1), diagram (Figure 1.2) and its key components BOM (Table 1.1) as follows:

1.1 Infineon PMSM EPS system program graph

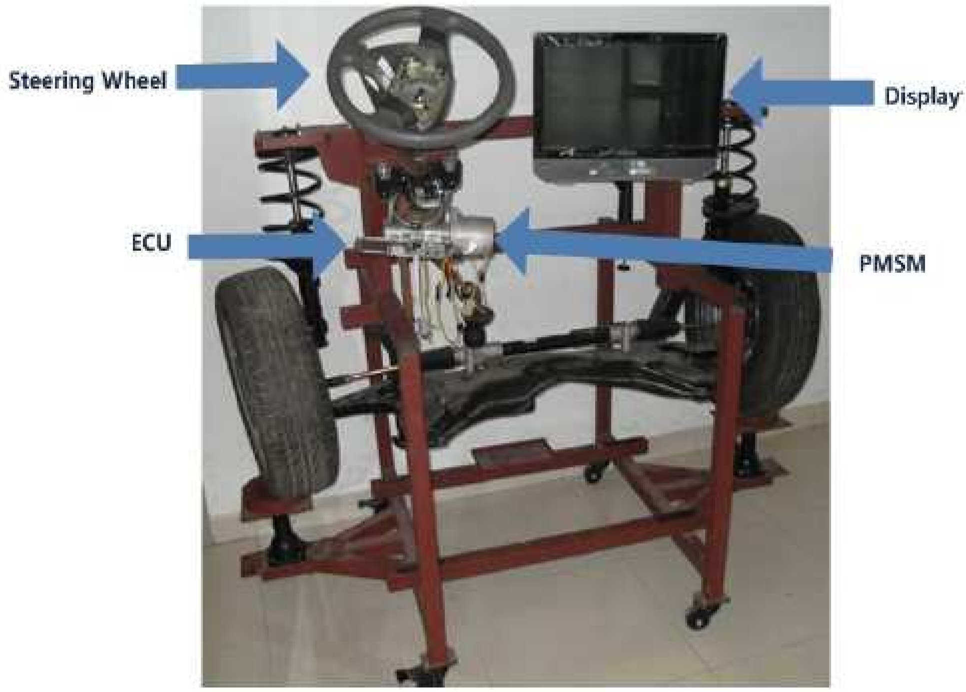


Figure 1.1 Infineon EPS system of permanent magnet synchronous motors

1.2 Infineon permanent magnet synchronous motor EPS system block diagram

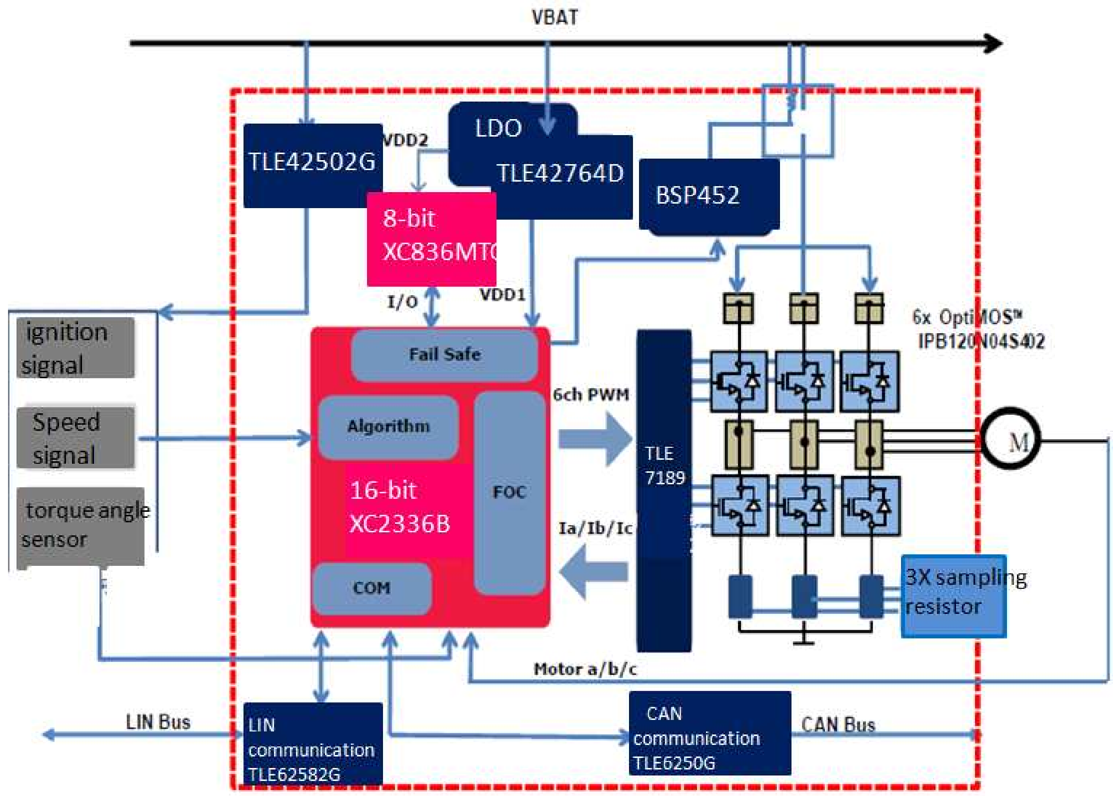


Figure 1.2 Infineon EPS system block diagram of permanent magnet synchronous motor

1.3 Infineon PMSM key component BOM EPS system

BOM table key components				
No.	Model	Brand	Function Description	Remark
1	SAK_XC2336B_40F8OL	Infineon	16/32 bit MCU for system control	
2	SAK_XC836MT	Infineon	8-bit MCU for system safety monitoring	
3	TLE4250-2G	Infineon	Linear power supply for the system sensor	
4	TLE42764D V50	Infineon	Linear power supply for the system sensor	
5	TLE6258-2G	Infineon	LIN communication chips	

6	TLE6250G	Infineon	CAN communication chips	
7	TLE7189QK	Infineon	Three-phase bridge driver chip used to drive six Mosfet	
8	IPB120N04S4-02	Infineon	Mosfet	
9	BSP452	Infineon	The high-side driver chips for bus precharging	
10	BVS-A-R002-1.0	RHOPOINT	0.001Ω phase current sampling resistor	
11	T6174	EPCOS	21uF power supply inductance	
12	B57702M0103A001	EPCOS	Temperature detection thermistor	
13	B41695A7228Q007	EPCOS	2200uF bus capacitor	
14	B82793C0513N201	EPCOS	Choker	

Table 1.1 Key components BOM

2 Infineon EPS system features permanent magnet synchronous motor

2.1 Infineon permanent magnet synchronous motor EPS system main parameters

• Applicable models：1.1～1.5T
• Operating Voltage Range：7～18V
• Maximum power supply input：1000W
• Controller output power: 550W（Typical）,900W（Maximum）
• Motor output torque: 6N.m（Typical），9N.m（Maximum）
• Motor speed range:20～2000 r/min
• System response time: < 100ms

• Over-current protection: 62A DC（TBA）
•PWM frequency: 20 kHz
• Over Temperature Protection:135℃(Mosfet)
• Operating Temperature： -40～+105℃

2.2 The main functions of Infineon permanent magnet synchronous motor EPS system

2.2.1 The main functions of the system work

• Assist control
• Damping Control
• Back to the positive control
• System communication functions
• System fault diagnosis function

2.2.2 Protection function

• Overvoltage Protection
• Under-voltage protection
• Over-current protection
• Over-Temperature Protection
• System Fault Protection

2.2.3 Communication function

•CAN communication
•LIN communication
•UART communication
• Other communications

3 Hardware

The system's main chips are used Infineon automotive-grade products. Mainly includes power supply, MCU, power control, communications, hardware interface and other parts.

3.1 Power

Power section contains a microcontroller, driver chips, communication chips power supply part, using TLE42764D V50. Further, since the EPS system is the safety control system, so the external sensors require a separate power supply, preventing external short circuits of the entire system. This power supply uses the power Infineon follower TLE4250-2G.

3.1.1 Master Power

Due to the master power supply related requirements need more 5 v power supply parts, such as host microcontroller, slave microcontroller, MOSFET pre-driver, CAN communication Transceiver, LIN communication Transceiver, UART communication Transceiver, a variety of pull-up circuit circuits. Therefore, considering the drive capacity needs, it requires a 400mA output capability of the LDO. In addition, the EPS system power supply is connected directly to the battery, which is not working when the vehicle is out of the open state power section, So when the vehicle does not work, want to let the system for a minimum power state, the best way is to get the power supply and out of sleep mode. Infineon consider these factors, added directly enable control functions to LDO, which enable function directly connected with the engine ignition signal to ensure that the engine operating state EPS system to begin to work. Main power supply section (shown in Figure 3.1.1) uses TLE42764DV50 with 400mA current output capability, which also has the enable control signal for engine ignition (IG) control.

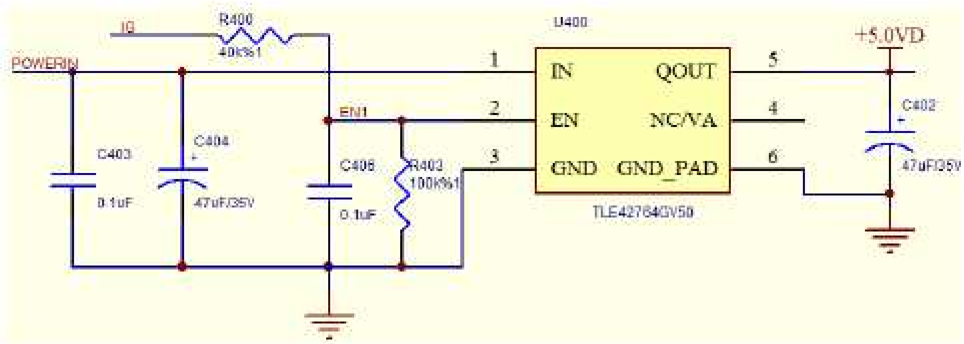


Figure 3.1.1 TLE42764GV50 master power supply circuit

When this system needs to be started, it needs the ignition signal connected to the 12 v power supply (12 v system ignition signal for 12 v). As the demo system did not join the ignition key control, so the signal is achieved by circuit board jump line directly above as shown in figure 3.1.2. When using external ignition signal, it can connect the ignition signal to the bottom through the jumper.

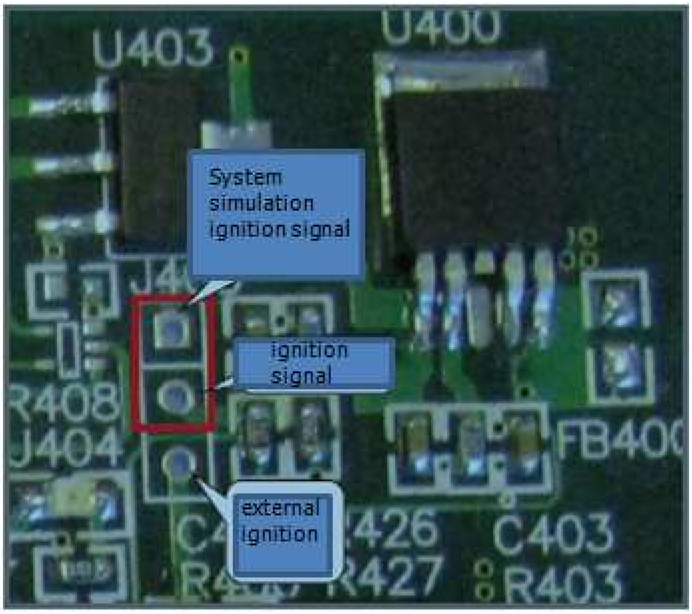


Figure 3.1.2 Ignition signal control circuit

3.1.2 Sensor power supply

Since the torque sensor and steering angle sensor is installed on the outside of the controller (string above in this system), so there is the risk of sensor supply short circuit, if the external sensor also uses the system main power supply, once the torque sensor shorted to ground, the power will cause the chip does not work, resulting in uncontrollable state for the entire system. Therefore, external sensors require a separate power supply, while the external torque sensor and angle sensor is an analog signal, you need to match with the main power system, so the selection of power follower TLE4250-2G. Its external sensor power supply circuit is shown in Figure 3.1.2.

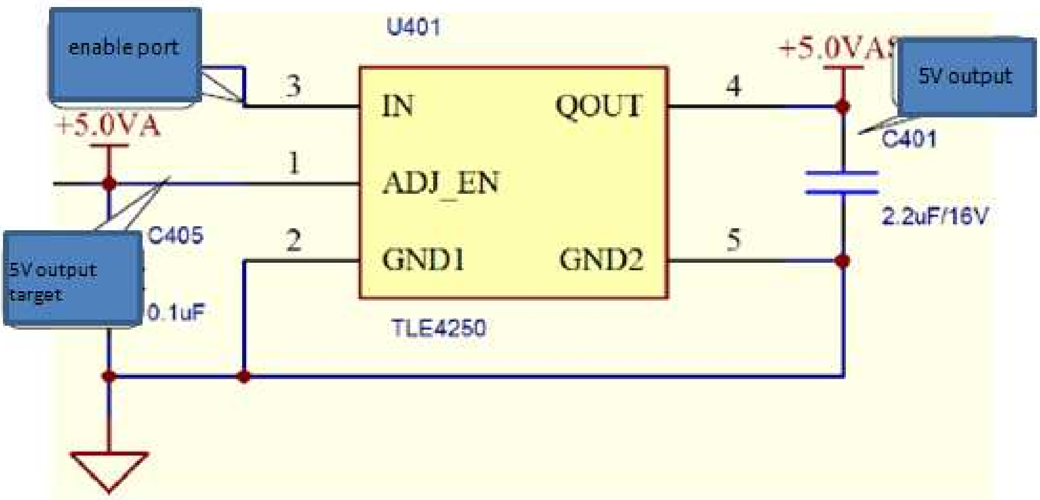


Figure 3.1.2 External sensor power supply

3.2 MCU

EPS is the security system, so the security and reliability requirements are relatively high, if the system has only one microprocessor control, then the microcontroller itself, hardware and software problems, its output state will be in a non-control state, seriously affecting the driver's personal safety. To prevent this safety hazard, the system uses a dual-chip, host microcontroller using XC2336B, slave microcontroller using XC836MT.

3.2.1 Host microcontroller

Infineon16 bit microcontroller XC2336B used primarily for security control, XC2336B for the LQFP-64 package, 80MHZ clock frequency, 320K Flash, 34K RAM, DSP functions, 38 IO ports, nine 12-bit precision AD, up to 20-channel PWM ports, an external bus interface, two CAN nodes, four universal serial communication (as a SPI, UART, ASC, IIC communication).

Although XC2336B is only 64 PIN package, but it has the resources which can use three-phase motor EPS system, including analog signal sampling, the digital signal input and output, etc. (resource allocation of the system as shown in Table 3.2.1).

NO.	Signal properties	XC2336B Port	Signal Interface	Function Remarks
1	Analog input	P5.10	SHUNT3	Phase current sampling
2		P5.8	SHUNT2	
3		P5.4	SHUNT1	
4		P5.0	POS2	Steering wheel angle position of the sampling
5		P5.2	POS1	
6		P5.15	T1MAIN	Torque sensor
7		P5.13	T2SUB	
8		P15.0	Temp	Temperature sampling system
9		P15.4	BP	Supply voltage sampling
10	Digital signal input	P10.8	QEPB	Motor Resolver Interface (standby)
11		P10.9	QEPA	

12		P10.10	HALLA	Motor HALL Position Sensor Interface
13		P10.11	HALLB	
14		P10.15	HALLC	
15		P2.7	7189_ERR2	MOSFET pre-driver fault feedback
16		P2.8	7189_ERR1	
17	Digital signal output	P10.0	CPU_IH1	PWM output port
18		P10.1	CPU_IH2	
19		P10.2	CPU_IH3	
20		P10.3	CPU_IL1	
21		P10.4	CPU_IL2	
22		P10.5	CPU_IL3	
23		P10.7	MainRelayOn	System protection relay control
24		P2.10	GPIO0	Communication with the XC836
25		P2.0	7189_ENA1	Enable MOSFET pre-driven
26		P2.2	GPU_Precharge	Enable sensor supply
27	Communication	P2.3	UART_TXD	Exports communication port
28		P2.4	UART_RXD	
29		P2.5	CAN_TXD	CAN communication port
30		P2.6	CAN_RXD	
31		P10.13	LIN_TXD	LIN communication port
32		P10.14	LIN_RXD	

Table 3.2.1 EPS system resource allocation table host microcontroller pin

3.2.2 Slave MCU

Taking into account the security of the system, and prevent failure of the main

microcontroller system caused by uncontrollable state, so the need to consider the use of an auxiliary microcontroller used as a monitor, ensure that the system in case of failure, the driver can still use mechanical steering system vehicle to vehicle maintenance point for maintenance treatment.

The system's slave microcontroller is using Infineon 8-bit high performance microcontroller XC836MT, TSSOP-28 package. The clock frequency is 24MHZ, 0.5K of RAM, 25 IO ports, 4 ADC channels, four PWM channels, 8K program memory space, a universal serial communication module, support for UART, LIN, SSC, IIC. Its distribution system port is shown in Figure 3.2.2.

NO.	Signal properties	XC2336B Port	Signal Interface	Function Remarks
1	Signal input	P0.4	7189_ERR2	MOSFET pre-driver fault
2		P0.5	7189_ERR1	MOSFET pre-driver fault
3		P1.3	7189_ERRn	MOSFET pre-driver total failure
4	Output control signal	P2.6	GPIO0	Communication with the host MCU port
5		P0.3		Fault indicator
6		P0.6	6250_INH	CAN communication transceiver enabled
7		P0.7	MON_MainRelayOn	Power protection relay control
8		P1.2	RESETn_836	The master microcontroller reset control
9		P2.3	EN1	Ignition signal detection ports
10		P2.7	CPU_MainRelayOn	Power protection relay control

Figure 3.2.2 the host microcontroller of slave EPS system pin resources allocation table

3.3 Power Control

This system uses permanent magnet synchronous motor, thus driven by three-phase bridge approach (as shown in Figure 3.3.1 and Figure 3.3.2). Since the motor power is 500W, the maximum operating power can reach 900W, system power supply of 12V. So it needs to reach maximum output current 75A or so. Taking into account the safety of the motor, when the current reaches 80A (power harness 80A fuse in series), the system is protected.

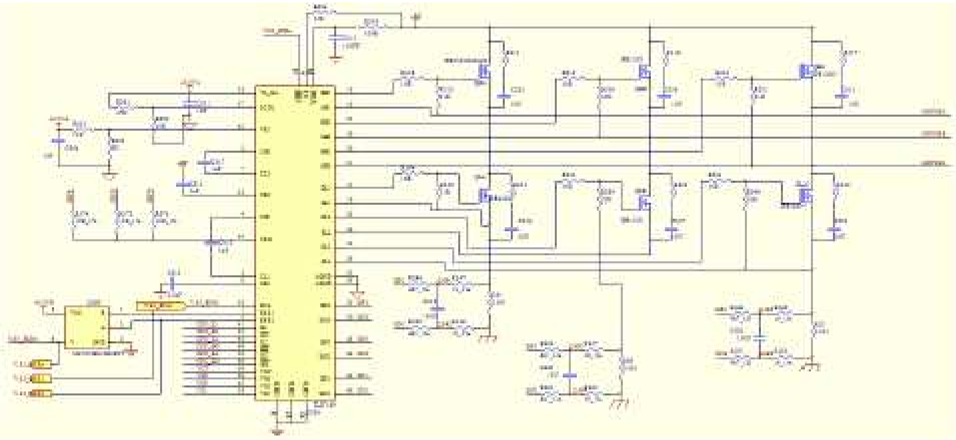


Figure 3.3.1 Power Driver Schematic

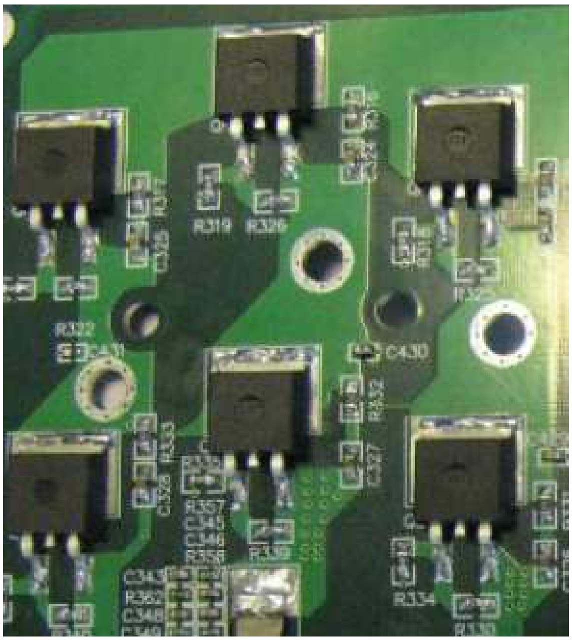


Figure 3.3.2 power drive circuit

Taking into account the current system may be operating at 80A, so the peak current is required even greater. And it is a 12V system, the peak voltage up to 38V, so MOSFET uses Infineon green car class IPB120N04S4-02. IPB120N04S4-02-resistance is only 1.8mΩ, sustainable operating current can reach 120A, Rthjc is only 0.9K / W, using

TO252-3 package. Therefore, this system has the advantages of a low heat, over current capacity, cooling capacity, etc.

MOSFET driver selection uses Infineon's TLE7189QK. Its main features are as follows:

- The PWM frequency can be to 30 KHZ
- 0 ~ 100% duty cycle
- Low sensitivity of EMC and EMI
- The control input for the TTL level
- For each MOSFET of the three phase bridge control alone
- Internal hardware dead zone
- Integrated three separate precision of op-amp
- Short circuit protection, short circuit current value can be adjusted
- Over temperature warning
- Detailed fault diagnostics
- Enable and Sleep Mode
- LQFP-64 package

Because TLE7189QK internal integrates three high-precision op amps, the current signal acquisition (as shown in figure 3.3.3) can be used in a way of MOSFET series resistance, and then process signals through TLE7189QK internal op amp. Two of the three signals as control signals, the third as calibration, test whether the sum of three signals' current is zero. Then transferred to the main control chip AD port analog to digital conversion. This can reduce systems the failure rate of using an external op amp, greatly improving the reliability of the system, but also reduces the system cost and PCB area.

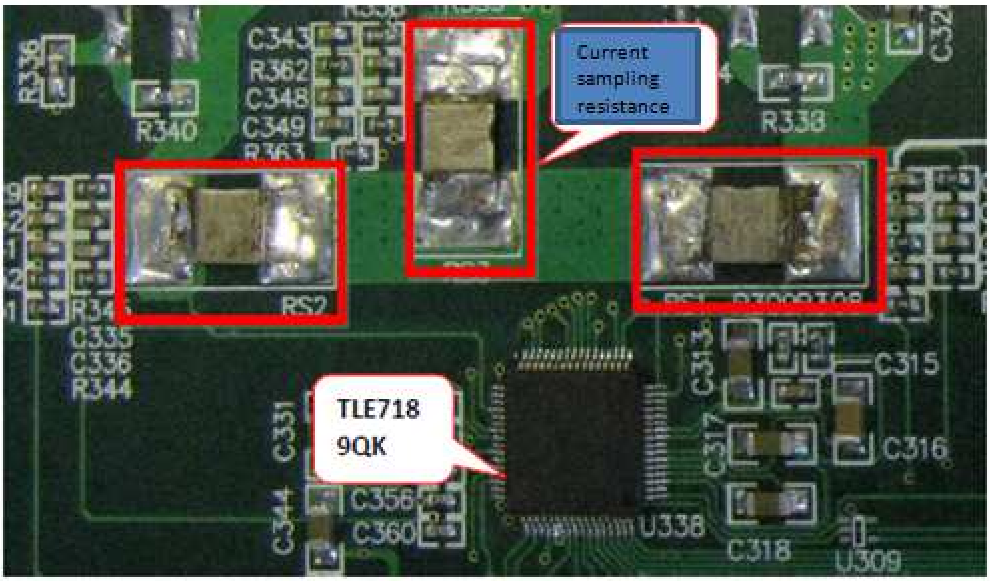


Figure 3.3.3 TLE7189QKand its current sampling circuit

3.4 Communications

EPS system is mainly used to communicate, including CAN, LIN, UART, etc., CAN communication is to achieve control center communication with the body, such as the

engine speed signal, the vehicle speed signal, etc., but can also communicate via CAN maintenance of the system, such as system upgrades, system status monitoring, and system fault information transmission. This system provides the three communications on hardware.

3.4.1 CAN communication

In this system, CAN communication (as shown in Figure 3.4.1.1 and Figure 3.4.1.2) is mainly used to transmit real-time operating parameters of the motor, including system Iq, Ia, Ib and the motor rotor angle, these few parameter transfer to the host computer, because the CAN communication is faster, Transmit information in real time, so debugging is very convenient.

High-speed CAN communication transceiver using Infineon's TLE6250G, support CAN communication protocol standard ISO11898-2 which can be used for 5V and 3.3V MCU control, but also has time to control. In the static mode, the quiescent current is less than 10uA, -40 ° C ~ 150 ° C wide temperature operating range, coupled with over-temperature protection, which can be used in a variety of automotive controller.

To be able to pass EMC and EMI, the CAN communication signal output, also joined by EPCOS choke.

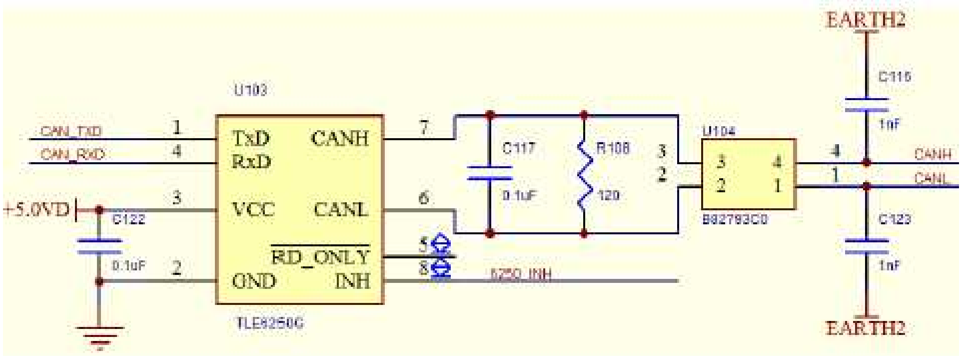


Figure 3.4.1.1 CAN communication diagram

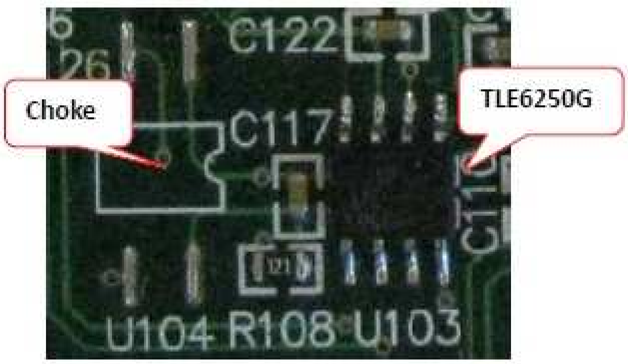


Figure 3.4.1.2CAN communication PCB diagram

3.4.2 LIN communication

LIN communication in the EPS system mainly associated with the communication between other devices, such as the communications between automotive instruments. LIN communication of the system (as shown in Figure 3.4.2.1 and Figure 3.4.2.2) only spare, the software does not use this feature. Transceiver using Infineon's TLE6258-2G, supports LIN / SAE J2602/k-line1.2, 1.3 and 2.0 standards and bus wake-up function, the transmission rate can reach 20kbit / s, which has enabled the control port, through the enable port which can guarantee it is in a low-power mode, when the bus is idle, and the quiescent current is less than 40uA. In protection, it has the function to prevent short-circuit proof to ground and short circuit to a power function, and over-temperature protection, mainly used in 12V system.

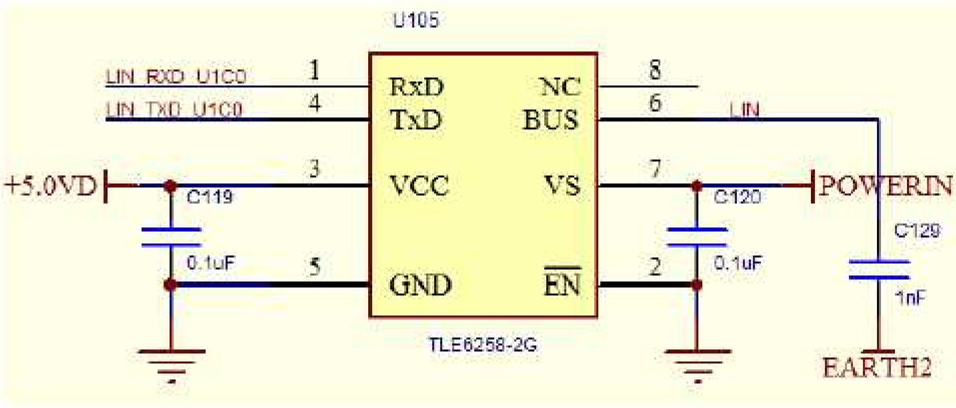


Figure 3.4.2.1 Schematic LIN communication system

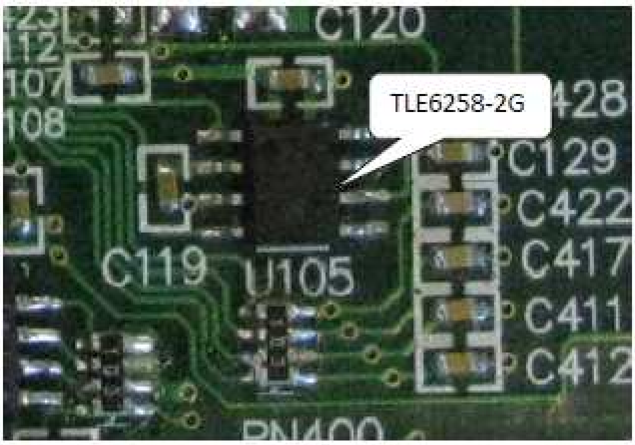


Figure 3.4.2.2 LIN communication system PCB diagram

3.4.3 UART communication

Traditional UART communication has been rarely used in the automotive electronic

control unit now, but this system in order to monitor the working status of the system, or whether the serial communication (as shown in Figure 3.4.3.1) joined them, mainly torque sensor torque upload system signal, the steering wheel angle signal, the power module temperature, motor current, motor rotor angle, the motor output torque, and receives a signal sent from the monitor display, such as the vehicle speed signal and engine speed signals. Meanwhile, Infineon microcontroller program can also be downloaded via the serial port upgrade, which can be used in the production process and the late upgrade.

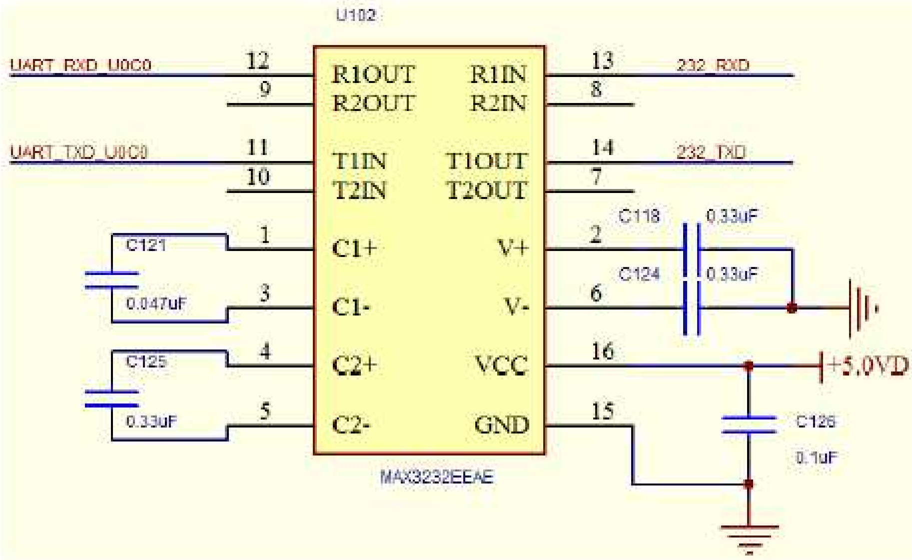


Figure 3.4.3.1 UART communication

3.5 Signal Acquisition

Because the system uses a permanent magnet synchronous motor, you need to collect three-phase current signal, and also had to collect the motor rotor position signal. Motor position sensors generally use three Hall-effect sensors, and there are also high-end products made using a rotary transformer rotor position sensor.

In addition to the motor itself signal acquisition, but also including torque sensor signal acquisition, steering wheel angle signal acquisition, supply voltage signal acquisition, power section temperature acquisition.

3.5.1 Digital Signal Acquisition

① HALL rotor position detection signal processing circuit (A, B, C with the same, as shown in Figure 3.5.1.1).

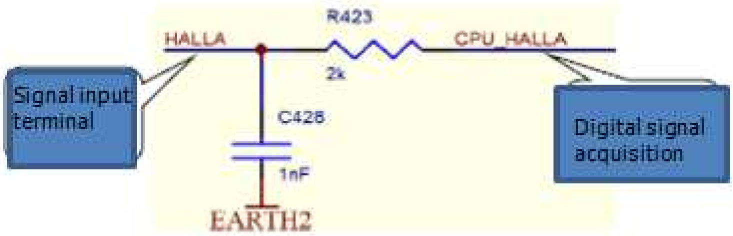


Figure 3.5.1.1

② Resolver signal processing circuit (shown in Figure 3.5.1.2), this circuit is alternative, in a system using a HALL way.

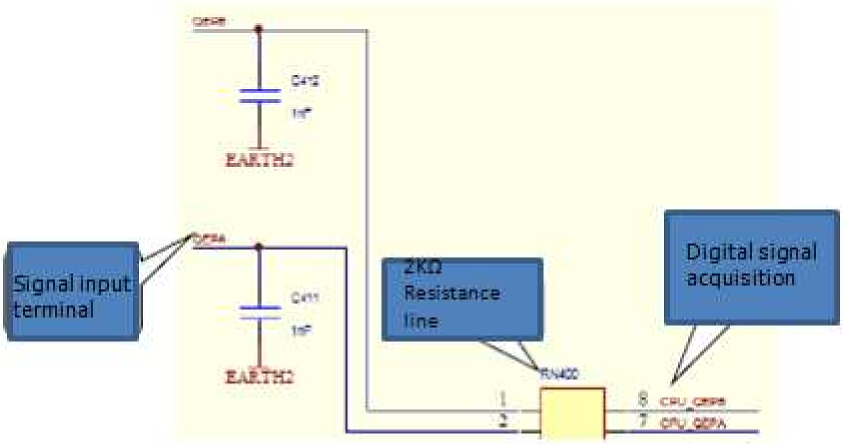
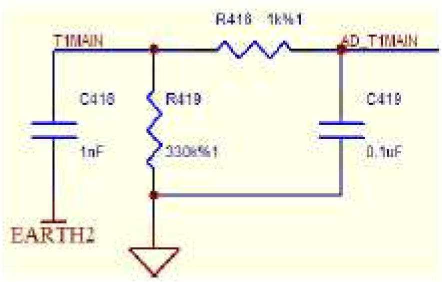


Figure 3.5.1.2

3.5.2 Analog signal acquisition

①Torque signal has two signal inputs, known as the main torque signal and sub torque signal. The two signals are complementary signals. The voltage of the Intersection of the two signals midpoint is 2.5V (5V power supply sensors), the hardware processing circuit shown in Figure 3.5.2.1 and Figure 3.5.2.2 as below.



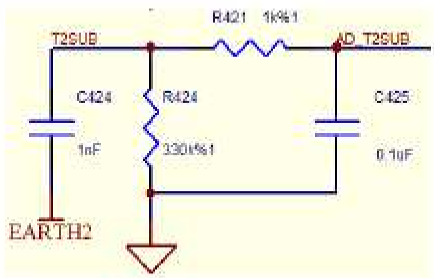
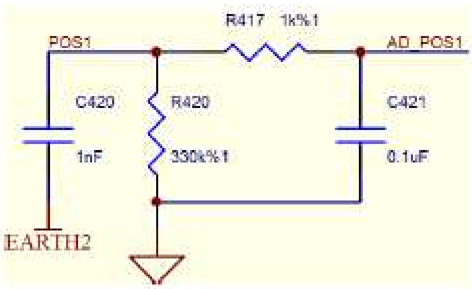


Figure 3.5.2.1 Main torque circuit Figure 3.5.2.2 sub torque circuit

② Torque signal with the same angle signal into two signals, which has a steering wheel angle signal and the number of turns of each coil angle signal, the hardware processing circuit shown in Figure 3.5.2.3 and Figure 3.5.2.4.



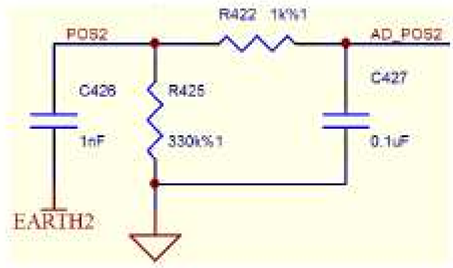
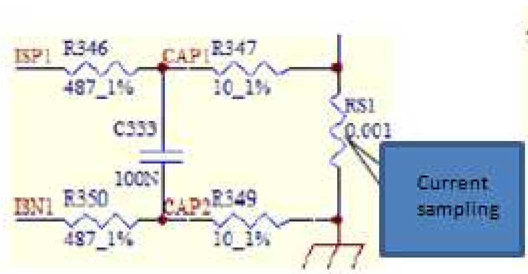


Figure 3.5.2.3 angle signal　　Figure 3.5.2.4 laps signal

③ Motor phase current vector control signal is a very important data, usually collected two current signals, obtained by calculating the first three-phase current path. As TLE7189QK op amp comes with a three-way, so the system in hardware made three-phase current sampling circuit. As shown in Figure 3.5.2.5 and 3.5.2.6.



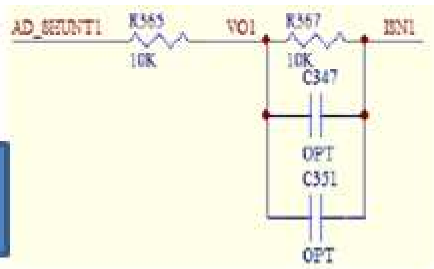


Figure 3.5.2.5 phase current op amp front　　Figure 3.5.2.6 phase current op amp rear

④ Supply voltage sampling, in order to detect whether the power system working properly, so the need for power supply voltage is sampled to ensure the system work in 8 ~ 18V. Because the system voltage 12V to 38V or more likely, while the microcontroller AD reference voltage is 5V, taking into account the system limits the peak voltage, so the use of 10KΩ and 1KΩ series, and then through 1KΩ resistor divider, the current sampling circuit shown in Figure 3.5.2.7.

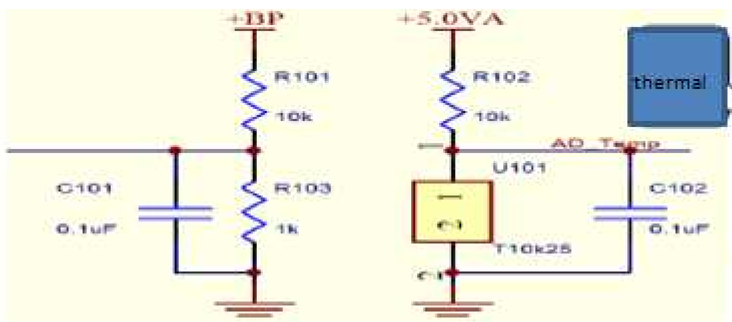


Figure 3.5.2.7 Power supply voltage acquisition　　Figure 3.5.2.8 power module temperature acquisition

⑤Power section temperature collection, use EPCOS thermistors as temperature sensors, this resistance can work in -40 ~ 125 ℃, the corresponding change in its resistance to 316181 ~ 3506Ω, processing circuit shown in Figure 3.5.2.8.

3.6 Interface Description

Power steering system controller with external devices connected to the system through the use of wire connections and plugs directly combined. Which signals associated with motor and torque signal, and the connected motor line is directly b connected through a wire cable. The system power supply and communication connect y the plug.

① Power and Communications Interface U402 (shown in Figure 3.6.1 and Table 3.6.1), the interface includes a power input interface, CAN communication interface, LIN communication interface, UART communication interface.

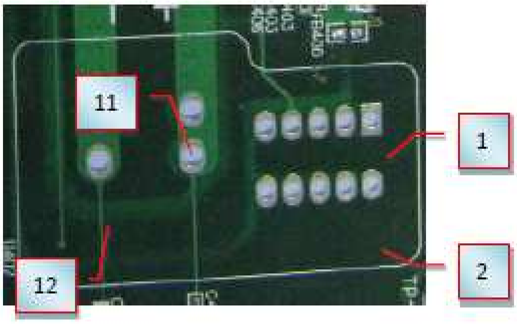


Figure 3.6.1 Power Supply and Communication Interface

U402							
Pin	12	11	9	7	5	3	1
Function	Power-	Power+	Unused	Ignition information	UART_RXD	CANH	+5V
Pin	12	11	10	8	6	4	2
Function	Power-	Power+	Unused	LIN	UART_TXD	CANL	GND

Table 3.6.1 Power and Communication Interfaces

②The controller is not connected to the motor phase plug, but the PCB directly connected (as shown in Figure 3.6.2), easy to install system connection. Using an external plug can save PCB area, and lower cost of external plug.

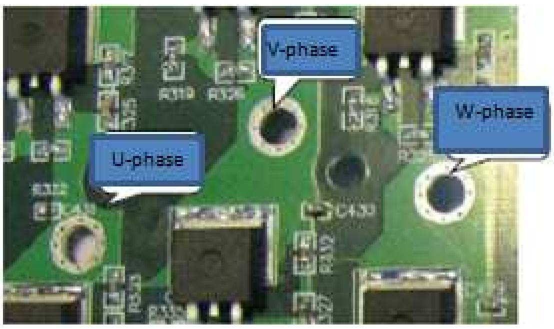


Figure 3.6.2 Power output connection

③ Rotor position detection signal interface U405B and U405A torque sensor signal interface is also directly connected to the outside (Figure 3.6.3 and Table 3.6.2), the controller does not use the plug housing.

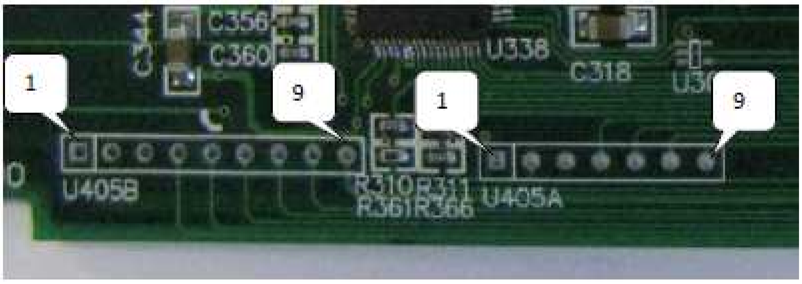
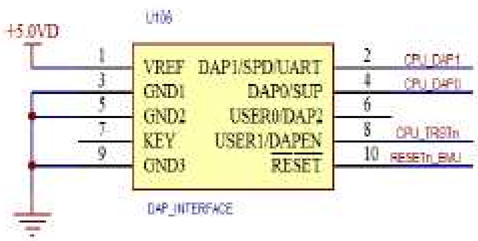


Figure 3.6.3 Power Output Connections

<table>
<tr><td rowspan="2">U405A</td><td>Pin</td><td>1</td><td>2</td><td>3</td><td>4</td><td>5</td><td>6</td><td colspan="3">7</td></tr>
<tr><td>Function</td><td>+5V</td><td>GND</td><td>X</td><td>Main torque</td><td>Vice torque</td><td>angle</td><td colspan="3">Steering wheel revolutions</td></tr>
<tr><td rowspan="2">U405B</td><td>Pin</td><td>1</td><td>2</td><td>3</td><td>4</td><td>5</td><td>6</td><td>7</td><td>8</td><td>9</td></tr>
<tr><td>Function</td><td>X</td><td>X</td><td>GND</td><td>resolver</td><td>resolver</td><td>HALL A</td><td>HALL B</td><td>HALL C</td><td>+5V</td></tr>
</table>

④ Chip debug interface

Host microcontroller XC2336B debug interface shown in Figure 3.6.4, when debugging, the SW100 all appropriated "ON" state, as shown in Figure 3.6.5.



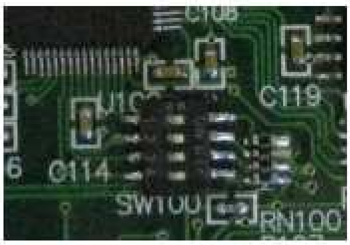


Figure 3.6.4XC2336B DAP debug interface Figure 3.6.5 debug mode selection

Monitoring microcontroller XC836MT debugging interface as shown in Figure 3.6.6, XC836's debug mode supports single pin DAP Debug mode, you can save IO port resources. In this circuit, the wire debug port is P3.2.

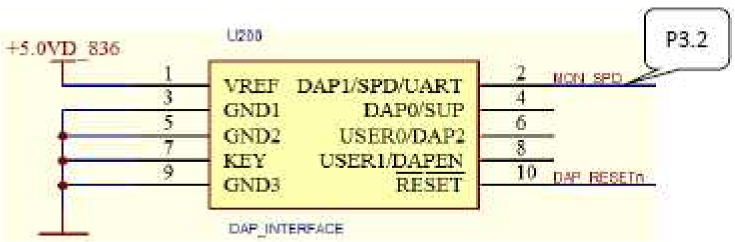


Figure 3.6.6 XC836MT single debug interface pin DAP

4 Software

After the System powers on (ignition signal is turned on), enter the system MCU and its peripherals initialization, and then enter the system control initialization procedure. System power waveform is shown in Figure 4.1.

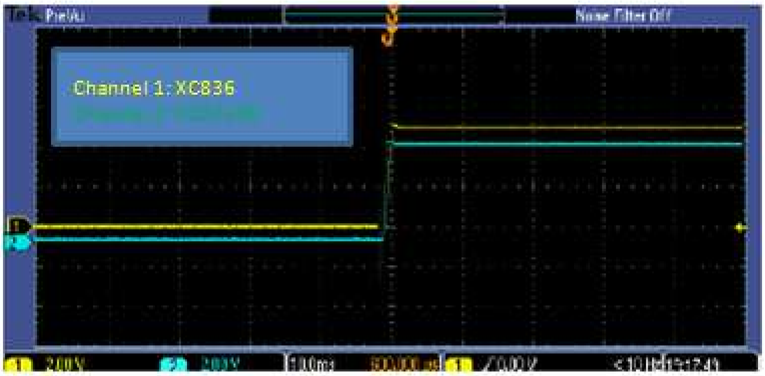
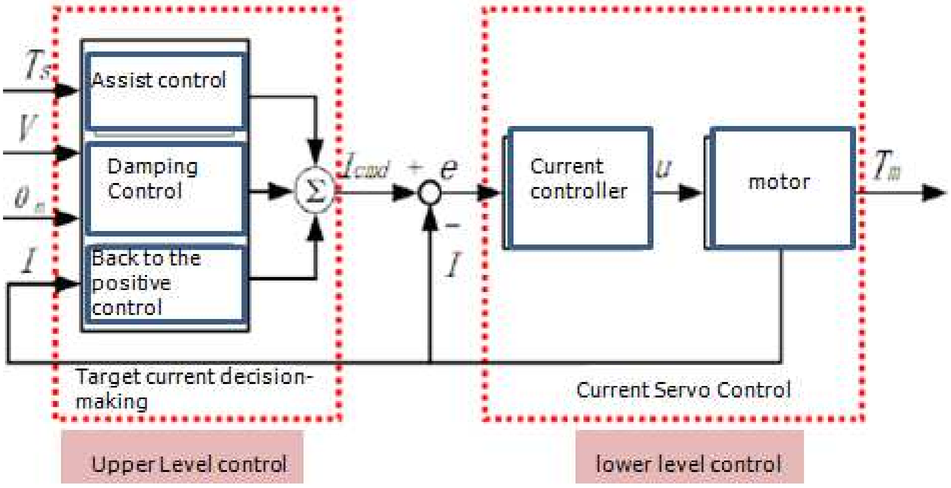


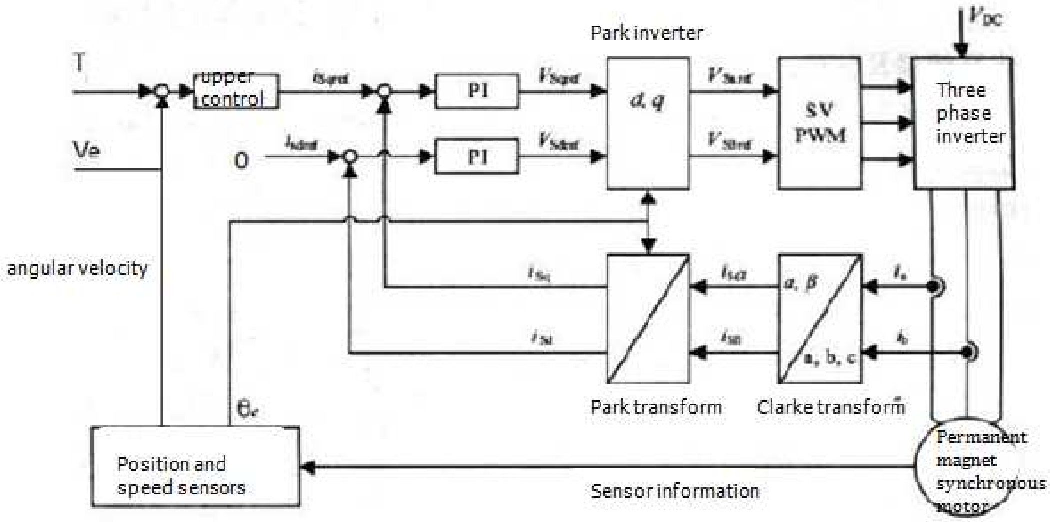
Figure 4.1 system powers on waveform

4.1 EPS control the main program

In the file name: `epscontrl.c, epscontrl.h`

The function of the EPS control the main program, call the EPS control of all relevant help, return, damping control strategy and permanent magnet synchronous motor control.

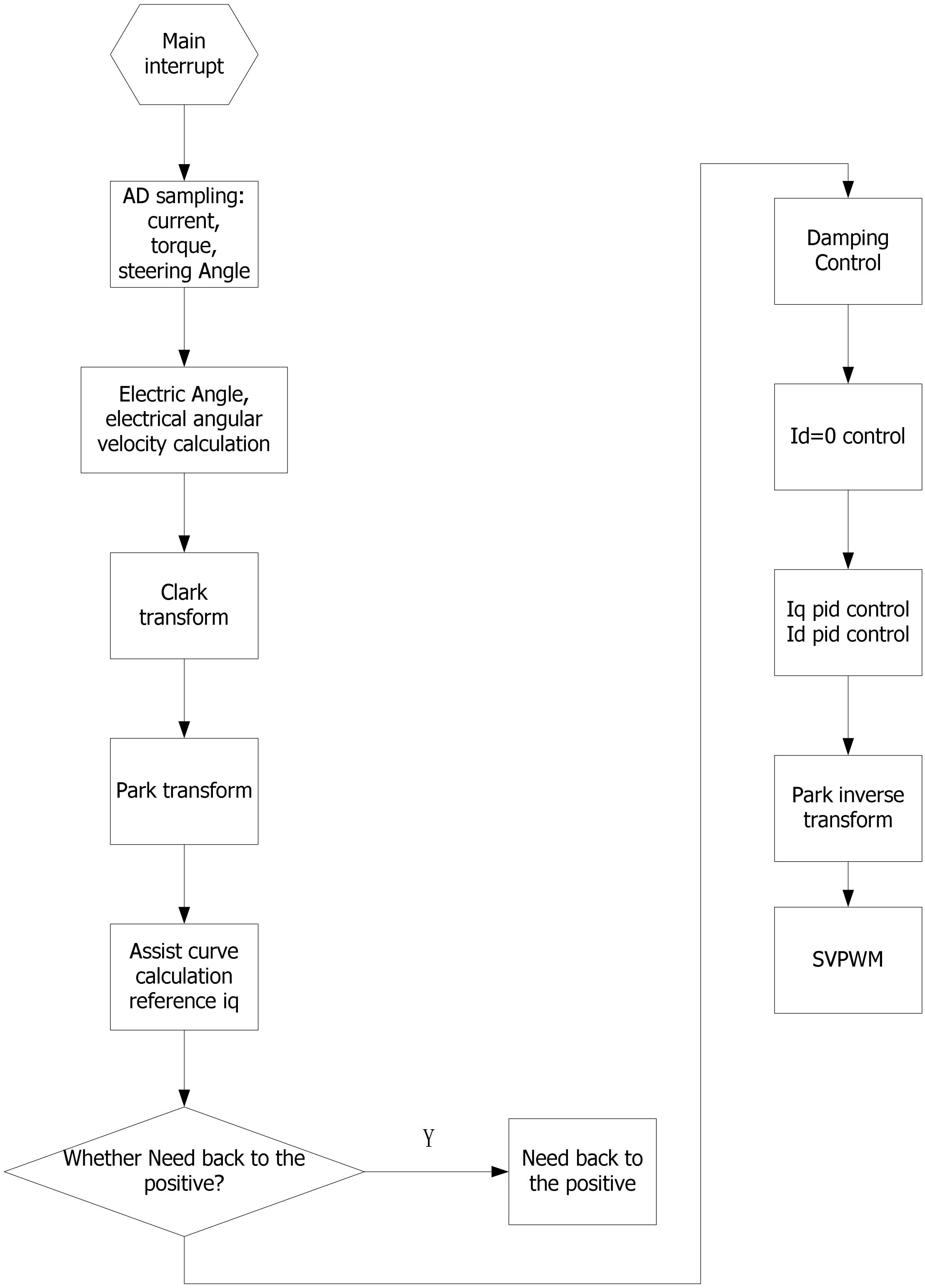




FOC algorithm block diagram of EPS

Description: EPS of FOC algorithm are generally the same, except that the torque current reference is from the EPS control strategy.

Main program flow chart:



4.1.1 void epscontrl_init()

Function Description:

Initialization procedure.

Call the method:

The Main () function calls a starting position, and does not perform in the future.

4.1.2 void EPS_Cal () execution

Call the method:

Each PWM cycle interrupt call at a time, in the file CCU60. C in the interrupt (CCU60_NodeI0_INT) void CCU60_viNodeI0 (void).

Period: 100us.

Program execution time is less than 60us, as shown in figure 4.1.2.

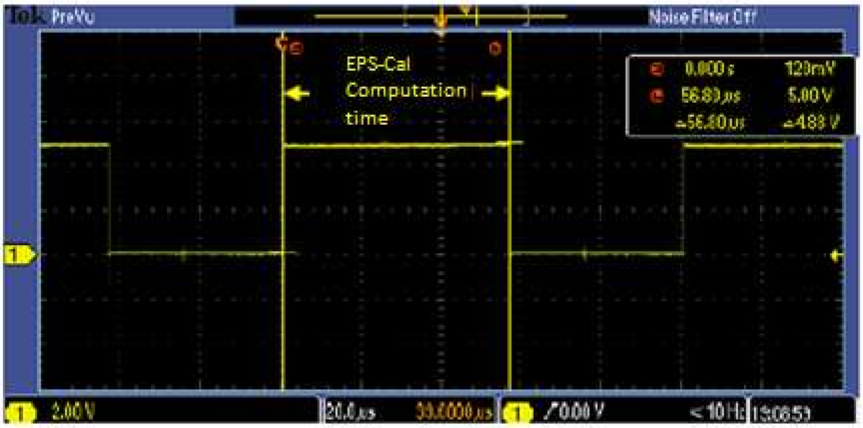


Figure 4.1.2EPS_Cal running time

4.1.3 Signal Sampling

In the file name: `sampling.c, sampling.h`

Program Description: This subroutine completed the initial sampling signal zero correction, digital format conversion. While achieving over current protection monitoring and cut-off function.

Calling method: Each EPS_Cal () is called once the program cycle.

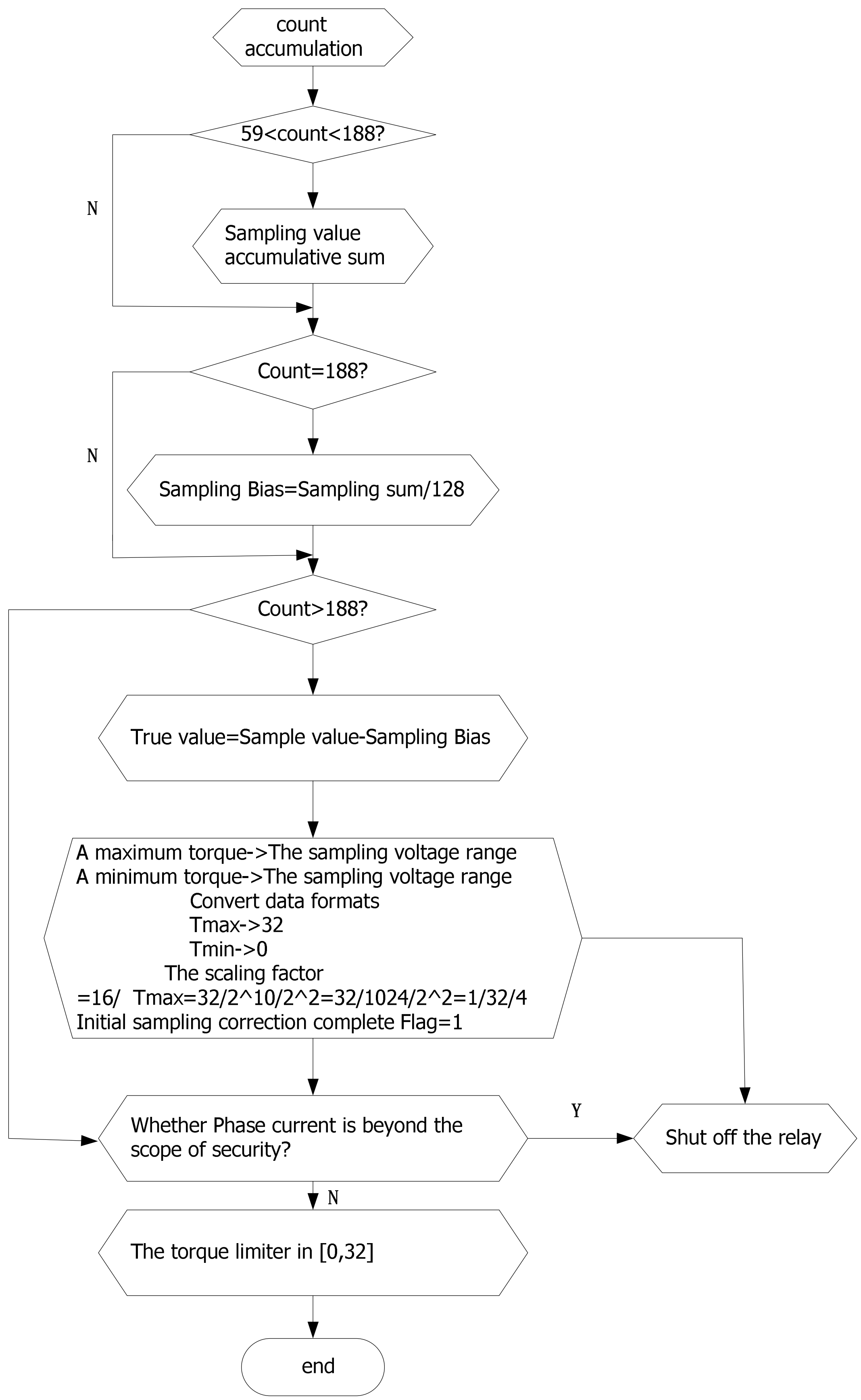
Variable definitions:

```
typedef struct{
        int ia; // A phase current is sampled, 62.5A -> Q15(1)
        int ib; //  B phase current is sampled, 62.5A -> Q15(1)
        int ic; //C phase current is sampled, 62.5A -> Q15(1)
        long ia0; // A phase corresponds to 0A current sampling offset value
        long ib0; //  B phase corresponds to 0A current sampling offset value
        long ic0; // C phase corresponds to 0A current sampling offset value
        int torque1; // Main torque corresponding sample values Torque voltage
(10%~90%)->(0~32)
        long torque10; // Main torque offset value corresponding to the sampling
```

```
        unsigned int TEMP; // Power zone temperature samples
        unsigned int count; // Cycle Count,(60~188) Intervals were calculated zero bias
        int ready; // Initialization completion flag

}SAMPLING;
```

Execution Flow:


count accumulation
59<count<188?
N
Sampling value accumulative sum
Count=188?
N
Sampling Bias=Sampling sum/128
Count>188?
True value=Sample value-Sampling Bias
A maximum torque->The sampling voltage range
A minimum torque->The sampling voltage range
Convert data formats
Tmax->32
Tmin->0
The scaling factor
=16/ Tmax=32/2^10/2^2=32/1024/2^2=1/32/4
Initial sampling correction complete Flag=1
N
Whether Phase current is beyond the scope of security?
Y
Shut off the relay
N
The torque limiter in [0,32]
end

4.1.4 PID regulator

In the file name: `pid.c, pid.h`

Program Description: This subroutine as EPS regulator control algorithm procedures to complete the Id, Iq current loop control

Calling method: Each EPS_Cal () is called once the program cycle.

Variable definitions:

```
typedef struct{ long err; // Deviation
                int fdb; // Feedback
                int ref; //reference
                long kp; // The scaling factor
                long ki; // Integrating factor
                long kd; // Differential Factor
                long kc; // Integral gain coefficient
                long up; // proportional
                long up_; // Previous cycle ratio
                long ui; // Integral item
                long outmax; //  Maximum output limiter
                long outmin; // Minimum output limiter
                long saterr; // Preliminary values of output
                int out; // Regulator output

}PID;
```

Control block diagram：

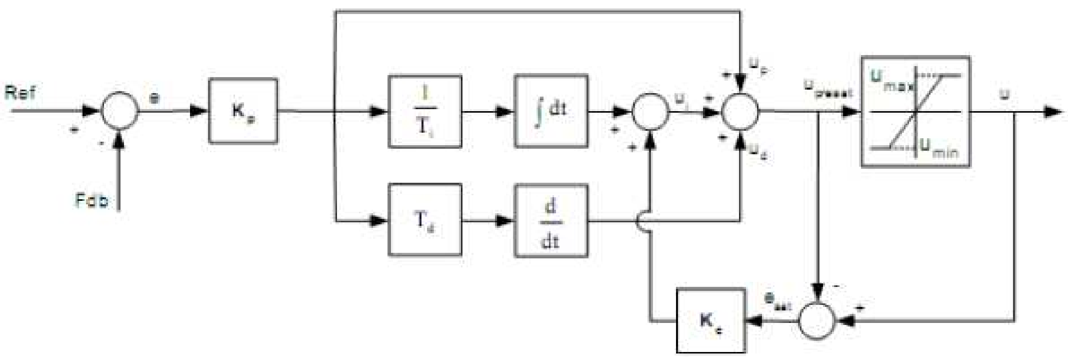


Figure1: Block diagram of PID controller with anti-windup

The formula:

$$u_{presat}(t) = u_p(t) + u_i(t) + u_d(t)$$
$$u_p(t) = K_p e(t)$$
$$u_i(t) = \frac{K_p}{T_i}\int_0^t e(\varsigma)d\varsigma + K_c(u(t) - u_{presat}(t))$$
$$u_d(t) = K_p T_d \frac{de(t)}{dt}$$

Among them:

u : PID controller output

u_{presat} : Output before anti-saturation

T_t : Integral time constant

T_d : Derivative time constant

K_c : Integral gain factor correction

4.1.5 Calculation of rotor position and speed

In the file name: `electricangle.h.c, electricangle.h`

Program Description: This subroutine finished calculating the position of the rotor and speed calculation.

Calling method: Each EPS_Cal () is called once the program cycle.

Variable definitions:

```
typedef struct{ int preangle;// Angle of the previous cycle
                int angle; // Current angle
                int wheelangle;// Steering angle
                int initcount; // Initialize the counter
                int qepcount; // Encoder counter
                int direction; // Direction of rotation
                int speed;// Rotor speed 1->523rad/s = 5000 Rev/min
Machinery
                int prespeed;// Rotor speed from the previous cycle
                int filterspeed;// Rotor speed after low pass filtering
                unsigned long time;// Two adjacent intervals code disk
                int captimer; // Capture moments
                int precaptimer; // Previous capture moments
                int ready; // Initialization completion flag
                int hall; // Hall state value
                int prehall; // State of the previous cycle Hall
}ELECTANGLE;
```

The lower three variables hall represents three Hall-effect states. Hall State transition position reflects the location of the rotor, so you can use these features to determine the point of the mechanical angular position of the rotor. As shown below, a total of six feature points:

```
1、 hall = 101 -> hall = 001, electang->qepcount = 6;
2、 hall = 011 -> hall = 010, electang->qepcount = 22;
3、 hall = 001 -> hall = 011, electang->qepcount = 14;
4、 hall = 110 -> hall = 100, electang->qepcount = 38;
5、 hall = 100 -> hall = 101, electang->qepcount = 46;
6、 hall = 010 -> hall = 110, electang->qepcount = 30;
```

Use the current and the previous cycle of the Hall to determine whether the state after the jump position is a relatively simple way.

A mechanical angle encoder signal period is 144; reducer ratio is 22, so the motor rotor turn around, turn the steering wheel 1/22 laps, the scope of activities of the steering wheel three laps, so each one and a half laps. Set the maximum steering angle of IQ15 (1), then the corresponding variable wheelangle code disc cumulative value 32768 / (33 * 144), steering wheel angle and the correspondence between the code wheel counter is `wheelangle = qepcount * 32768 / (33 * 144) = qepcount * 6.89`, rounded coefficient after `wheelangle = qepcount * 6.`

The motor is a 3 pole pairs, so code disk counters every increase or decrease in 144/3 = 48 values turned a power cycle. To calculate the electrical angle encoder counter divisible by 48 using the remainder of the way to get the code disk counters with the position of the rotor relative relationship. Then use the scale factor obtained rotor position. IQ15 format using the electrical angle, scale factor of 32768/48 = 682.666 = 682.

Use the rotor angle values after two cycles compared to judge the rotational direction, but pay attention at 360 degrees, 0 degrees where the hopping require special handling.

Rotor speed calculation method: After each rotor between two adjacent time code disc mechanical angles of 2.5 degrees can be obtained by dividing the rotor speed, finally, the speed value pass low filter.

Angular separation between the adjacent code disc mechanical angle of 2.5 degrees, turn the rotor disc adjacent code if more than one minute intervals, namely that the velocity is zero; If the interval is less than 100us, is equal to 100us, because the maximum speed of the rotor is not exceed `2.5/0.000001 = 2500000deg / s = 416666r/min.`

For normalized velocity value set maximum speed of 5000r/min = 30000deg / s, that is within the program `IQ15 (1) = 32768.` Conversion factor = `1deg/s/30000deg/s = 33.3333 * 10 ^ -6.`

In order to more accurately calculate the turn adjacent interval between code disk, to consider the capture time stitching.

4.1.6 CLARKE transform

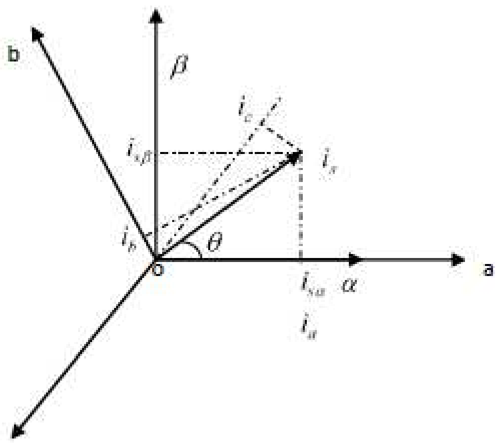
In the file name: `clarke.c, clarke.h`

Program Description: The standard three-phase coordinate system is converted to two-phase Cartesian coordinate system conversion formula

Calling method: Each EPS_Cal () is called once the program cycle.

The formula is:

$$\begin{bmatrix} i_{s\alpha} \\ i_{s\beta} \end{bmatrix} = \begin{bmatrix} 1 & 0 & 0 \\ 0 & \frac{1}{\sqrt{3}} & -\frac{1}{\sqrt{3}} \end{bmatrix} \begin{bmatrix} i_a \\ i_b \\ i_c \end{bmatrix}$$



4.1.7 PARK Transform

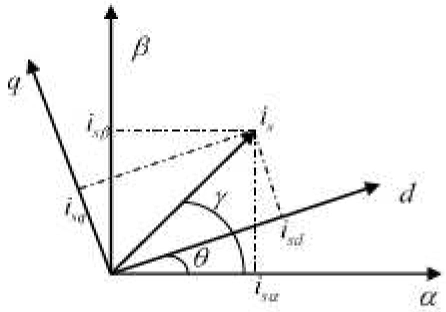
In the file name: `park.c, park.h`

Program Description: The standard two-phase stator coordinate system to the two-phase rotor coordinate system conversion

Calling method: Each EPS_Cal () is called once the program cycle.

The formula is:

$$\begin{bmatrix} i_{sq} \\ i_{sd} \end{bmatrix} = \begin{bmatrix} -\sin\theta & \cos\theta \\ \cos\theta & \sin\theta \end{bmatrix} \begin{bmatrix} i_{s\alpha} \\ i_{s\beta} \end{bmatrix}$$



4.1.8 IPARK transform

In the file name: `ipark.c, ipark.h`

Program Description: PARK inverse transform

Calling method: Each EPS_Cal () is called once the program cycle.

4.1.9 Trigonometric calculations

In the file name: `math_m.h`，`math_m.c`

Program Description: Only established range 0-90 degrees in the sine function table, the other angle cosine directly alluding to the 0-90 range, the calculated its value.

4.2 Assist control

In the file name: `assisttable.c, assisttable.h`

Program Description: This subroutine completed basic EPS boost function table method to achieve different speeds, different moments practicing hand under the help. The power curve is the reference curve (Figure 4.2), you can adjust the size according to the driver's experience, changing the severity of practicing hand.

Calling method: Each EPS_Cal () is called once the program cycle.

Data Format: IQ15, the figure for each color represents a speed boost under the curve, gradually decreasing from the top down.

Data in the table represent physical meaning: Let Q15 (1) = 62.5A, 62.5A current sample voltage corresponding to Q15 (1) corresponding to the sampled value (2 ^ 15 = 32768), so the two equivalents. Characterization of the physical meaning of 20000 is, 20000/2 ^ = 20000/32768 = 15 Q15 (0.61) = 0.61 * 62.5 = 38.14

A.

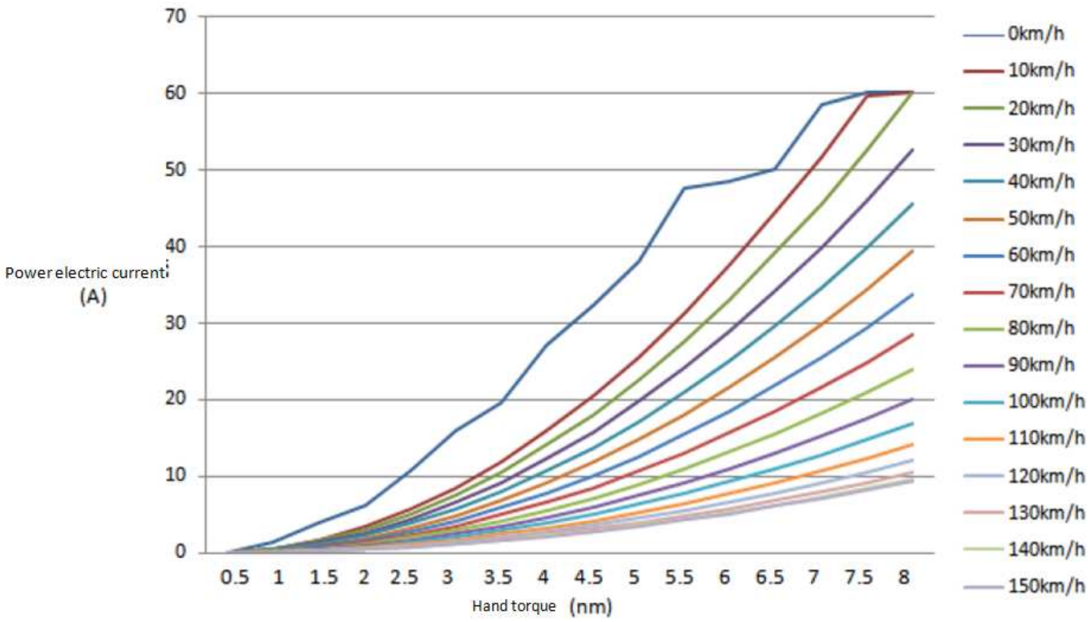


Figure 4.2 assist control curve

4.3 Damping Control

In the file name: `damp.c,damp.h`

Program Description: This subroutine completed damping control function under different speed.

Calling method: Each EPS_Cal () is called once the program cycle.

Damping current I = - damping * motor speed

Damping control coefficient map:

The picture shows the reference debug curve (Figure 4.3), each point can vary with different models for debugging. The main purpose is to solve the car at high speed when the damping is too small and the steering system center unstable. So low active damping is small and high-speed large. Debugging personnel can be resized based on the actual situation.

Data in the table represent physical meaning: Let Q15 (1) represents the maximum damping factor, the characterization of the physical meaning 20000 is `20000/2 ^ 15 = 20000/32768 = Q15 (0.61)`, 0.61 represents the maximum damping.

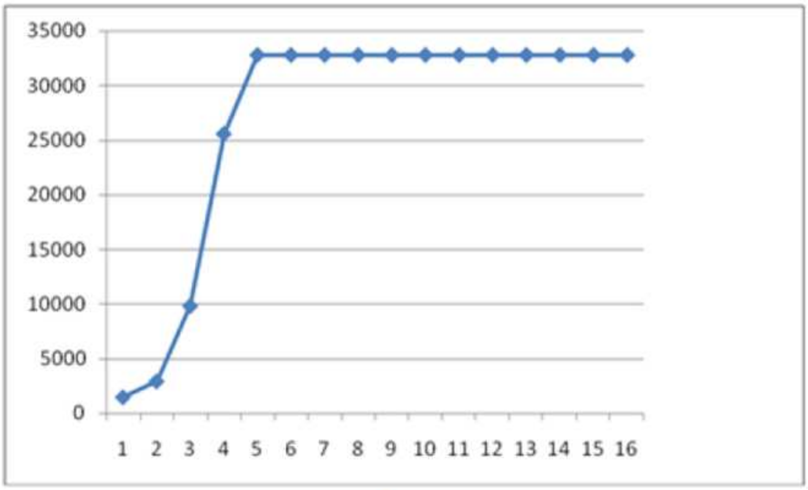


Figure 4.3 damping control curve

4.4 back to the positive control

In the file name: `return.c`, `return.h`

Program Description: This subroutine completed the medium speed (14 ~ 69km / h) under the initiative back to the positive control function

Calling method: called one time when the back is marked as 1.

Variable definitions:

```
typedef struct{ int ang;  // steering wheel Angle
                unsigned int ve;  // The speed of the car
                int speed;  // The rotor speed
                int out;  // Back to the positive voltage
                int angintegr;// Integral item
                int torq;  // The steering wheel torque
                int start;  // Start back flag
                unsigned int keeploosen;  //loosen time
} RET;
```

Correction coefficient of speed control

Adjust the return-to-center control curve (as shown in figure 4.4.1) can control the correction speed, maximum IQ15 (1) (32768) represents the fastest speed. Adjusting Speed back to different speed according to the driving experience, let the return-to-center performance to achieve optimal state.

Back to positive voltage = correction speed coefficient (KP * ang + ∑ ki *ang); Through the formula to adjust back to positive voltage;

PID debugging general steps:

a. Determine the proportional gain P

Determine the proportional gain P, the first to remove the PID integral and

differential terms, generally let Ti = 0, Td = 0 (see specific instructions PID parameter setting), the PID for the pure proportional control. Input is set to the 60% to 70% of the maximum allowed by the system, gradually increase the proportional gain P starting from 0, until the system oscillates; another turn, from the proportional gain P gradually decreases until the oscillation disappears, recording the proportional gain P at this point, set the PID proportional gain P is the current value of 60% to 70%. Proportional gain P commissioning completed.

b. Determine the integration time constant Ti

Proportional gain P is determined, set a larger initial value of the integral time constant Ti, and then gradually decreases Ti, until the system oscillates, after which, in turn, gradually increasing Ti, until the system oscillations disappear. Record the Ti, set the PID integral time constant Ti is the current value of 150% ~ 180%. Integral time constant Ti commissioning completed.

c. Determine the derivative time constant Td

Integral time constant Td is generally not set to 0. To set up, the same way as the method of setting P and Ti, taking 30% of the time when it does not oscillate.

d. System load, load the FBI, and then fine-tune the PID parameters until satisfied.

Data in the table represent physical meaning: Let Q15 (1) represents the fastest speed, the characterization of the physical meaning of 30000 is `30000/2 ^ 15 = 30000/32768 = Q15 (0.91)` which represents the fastest speed of 0.91 times.

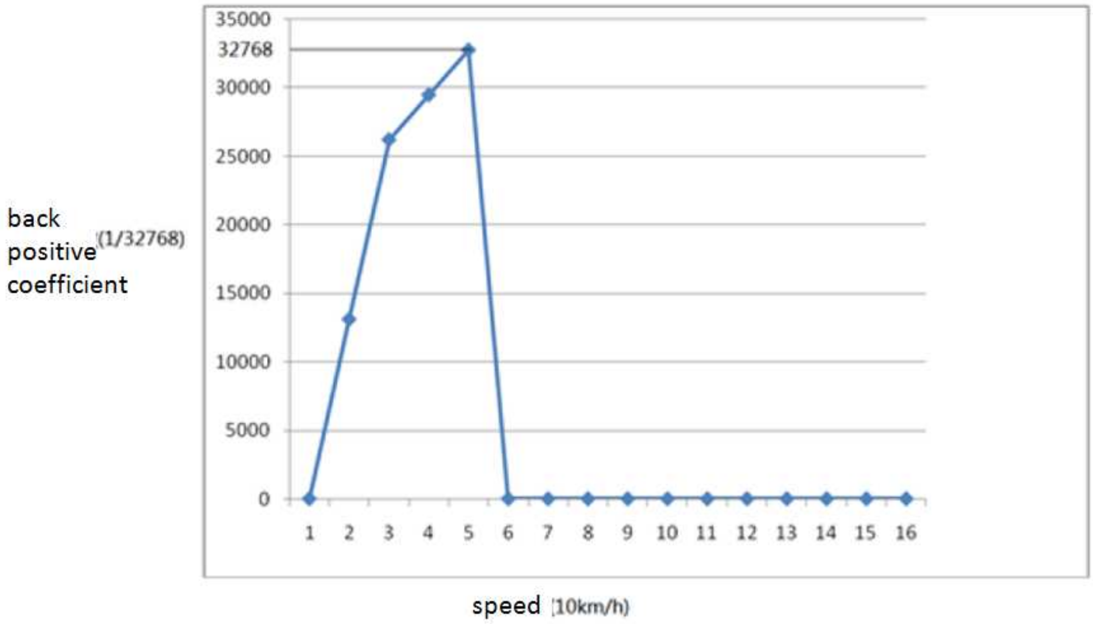


Figure 4.4.1 back to the positive control curve

Flowchart:

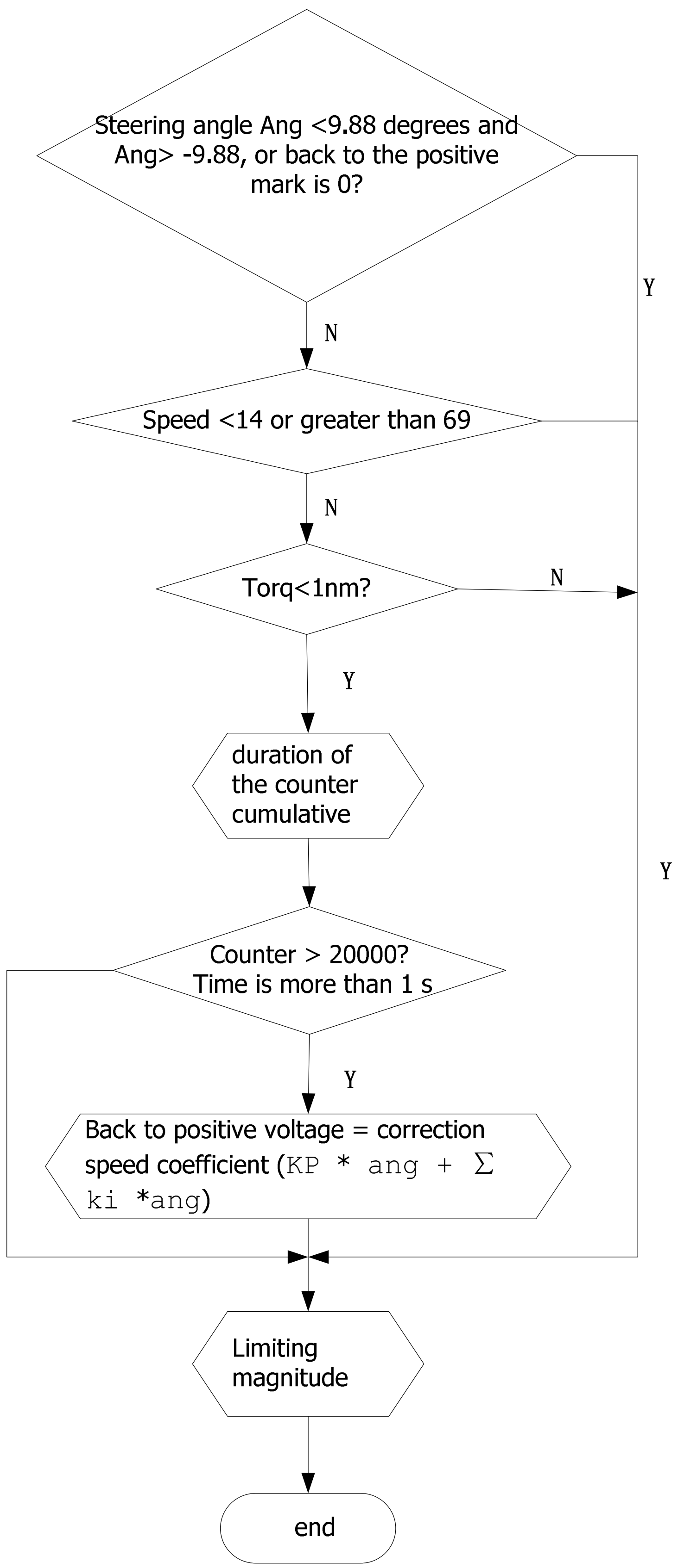


Figure 4.2.2 back to the positive control flow

Back to the positive debugging method: proportional kp decided to return a positive

response rate, the greater the proportion of items, return faster, but easy to overshoot, if there is overshoot, then transfer a small proportional term; integral term decided to return to a positive residual angle , if a return is insufficient, increase the integral coefficient ki.

4.5 Communications

4.5.1 Serial Communication

In the file name: `main.c`

Program Description: This code implements the function of communication with the host computer.

Call the method: the main program loop waits, sending and receiving data when idle.

Communication protocol:

Receiving protocol:

Packet	header	the checksum	End of Frame	
CMD3	INT16	INT16	*	/ / receives vehicle speed information.

Parity (XOR): the checksum = Packet ^ character 3

Transmission protocol:

Packet	header	the checksum	End of Frame
55	INT16	INT16	AA

Parity (XOR): Checksum = Data 0 ^Data 1 ^ .... ^ 8 data.

4.5.2 CAN communication

Interface Description

utility.c the two functions.

```
void vCAN_Transfer (unsigned char * p)
```

This function is used to transmit CAN data

```
void vCAN_Receive (CAN_PACKAGE_PTR CanPackagePtr)
```

This function is used for data reception.

This function uses the CAN structure is:

```
typedef struct
    {
        unsigned long u32CAN_ID;
        unsigned char u8CAN_LEN;
        unsigned int u16CAN_DATA[4];
    } CAN_PACKAGE;
```

```
u32CAN_ID; // CAN ID of the packet
u8CAN_LEN; // CAN data packet length
unsigned int u16CAN_DATA[4]; // Packet storage array
```

4.6 Fault Diagnosis and Protection

System mainly includes Over-current protection, Over-voltage Protection, Under-voltage protection, Over-Temperature Protection, pre-drive TLE7189QK hardware protection.

4.6.1 Over-current protection

System is used for controlling the phase current to the motor, but the acquisition of the two-phase current, the third phase current can be calculated. Therefore, in the acquisition of two-phase current, once one phase current exceeds 62A, it will disconnect the power section supply (relay disconnected) to guarantee fast shutdown of the system and timely current protection in order to protect the motor effect.

4.6.2 Over-voltage Protection

Since the system supply voltage may be unstable, especially in the case of magneto unstable, its supply voltage can reach more than 38V. Therefore, the system requires real-time monitoring system voltage, and makes the appropriate protection. By monitoring the system input voltage, when the system voltage reaches 18V or more, it will disconnect the power section supply (relay disconnected) to protect the pre-drive TLE7189QK and MOSFET.

4.6.3 Under-voltage protection

EPS working at large angles as the turn, which requires relatively large current, can reach more than 60A. If the voltage is low, the output is still such a large current, and then it will seriously shorten the battery life. Therefore, when the voltage is low, it also needs protection. So it will disconnect the power supply section (relay disconnected) to protect the system battery.

4.6.4 Over-Temperature Protection

Vehicles entering the mountain drive, it takes a long period of sustained turn. At this time EPS system continued working current is large. The power part of the EPS system therefore severe fever, because it is not timely cooling, the temperature will cause the power section increasing rapidly. If you do not monitor and protection, when the

temperature rises to a certain time it will affect the system performance, severe burning power devices. Therefore, the system monitors the temperature reaches 135 ℃ bottom MOSFET, it will disconnect the power section supply (relay disconnected) to protect the pre-drive TLE7189QK, MOSFET and its surrounding parts.

4.6.5 Pre-driving TLE7189QK hardware protection

Because software protection rapid response is limited, in addition to software protection system, another TLE7189QK inherently fast over-current, over-voltage, over-temperature protection automatic hardware, software and hardware can be achieved simultaneously monitor dual protection.

4.7 xc836

XC836 communication with XC2336B, primarily achieve through an IO port. SCM function is currently reading xc2336B relay control signal, 7189_ERRn, 7189_ERR1, and 7189_ERR2. Then the LED display four signal levels. XC836 does not participate in the specific power control, damping control, back to the positive control and communication functions with the host computer, and its main function is to monitor the master chip XC2336B, and is responsible for controlling TLE7189QK the 7189EN, and non-normal working hours in XC2336B be reset and the alarm function.

4.8 System Dual MCU software work strategy

The master system implemented by the XC2336B assist control, damping control, back to the positive control, system status information is uploaded, the control parameters received and so on. And sub controlled by the XC836 to achieve control XC2336B's work, mainly through the IO communication judging XC2336B whether working properly, once XC233B has not XC836 communications, is considered the master MCU to operate normally, need to be reset, if still does not work after trying to reset, you need to completely close the whole controller's power section and alarm the user to do maintenance.The specific process is as follows:

1, after powers on, XC2336 control relay on (CpuMainRelayOn = 0);
2, XC836 detects CpuMainRelayOn, when it is "0", McuMainRelayOn = 0;
3, the 7189en of XC836 as outputs. Enable the 7189EN of TLE7189QK.
4, XC2336's 7189en pin set as input. XC2336 detection 7189en is high, TLE7189QK start normal operation by INH enabled.
6, when MCU found 7189 ERR pin in fault state, close the 7189EN of TLE7189QK.
7, XC2336B found EN is "0", close off INH and the relay.

Communicate with each other work process is as follows:

1, in normal operation, XC2336B periodic inverted status of GPIO.

2, if the XC836 found XC2336B doesn't normal turn over within a certain time, then close off the 7189EN of TLE7189QK.

3, test for XC2336B reset.

4, if 3 consecutive reset XC2336B, XC2336B, it still does not work, then will close the 7189EN of TLE7189QK, alarm and display.

After XC2336B powers on, PORT2 = 0X0x0004, PORT10 = 0x0080

The process of XC2336B handshake with the XC836 is

XC2336B		XC836
1 An open relay is enabled (P10.7 = 0)	---------->	Waiting XC2336B open relay enable
2 GPIO set 1		open TLE6250, enable TLE7189QK
3 Wait XC836 enable TLE7189QK	<----------	waiting GPIO = 1
4 Enable TLE7189QK (INHn = 1)	---------->	Waiting XC2336B the GPIO is set 0
5 GPIO set 0	---------->	begin monitoring.

5 monitors display interface

In order to intuitive monitoring in the system working condition, the system uses an external monitor for visual display. It mainly consists of torque signal of the torque sensor system, steering wheel angle signal, the power module temperature, motor current, motor rotor angle, the motor output torque. The interface can be adjusted directly on the analog speed signal (Figure 5.1 and Figure 5.2)

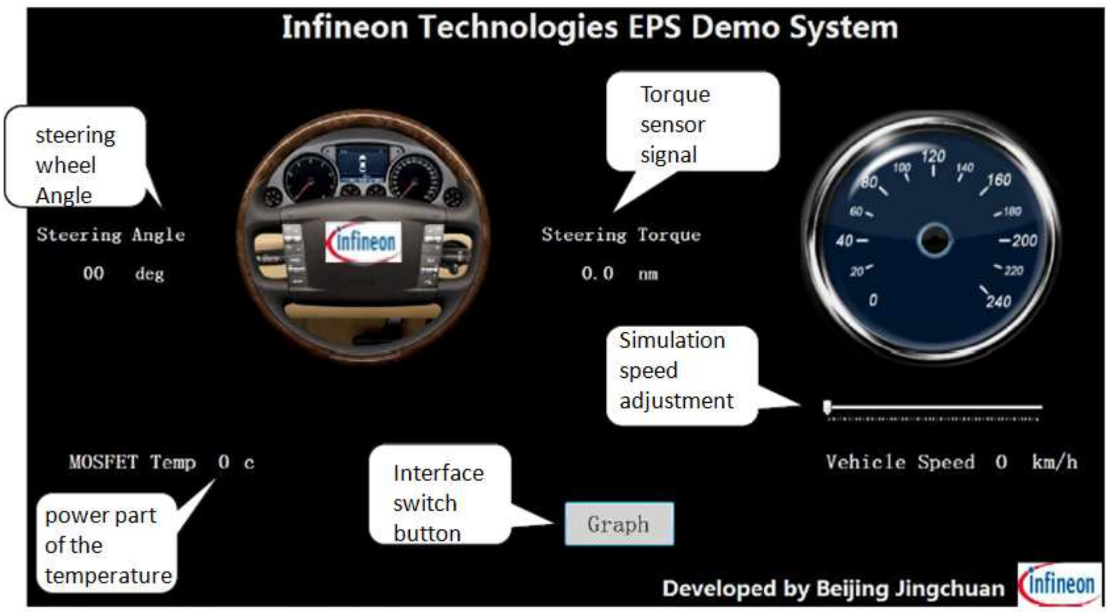


Figure 5.1 digital display interface

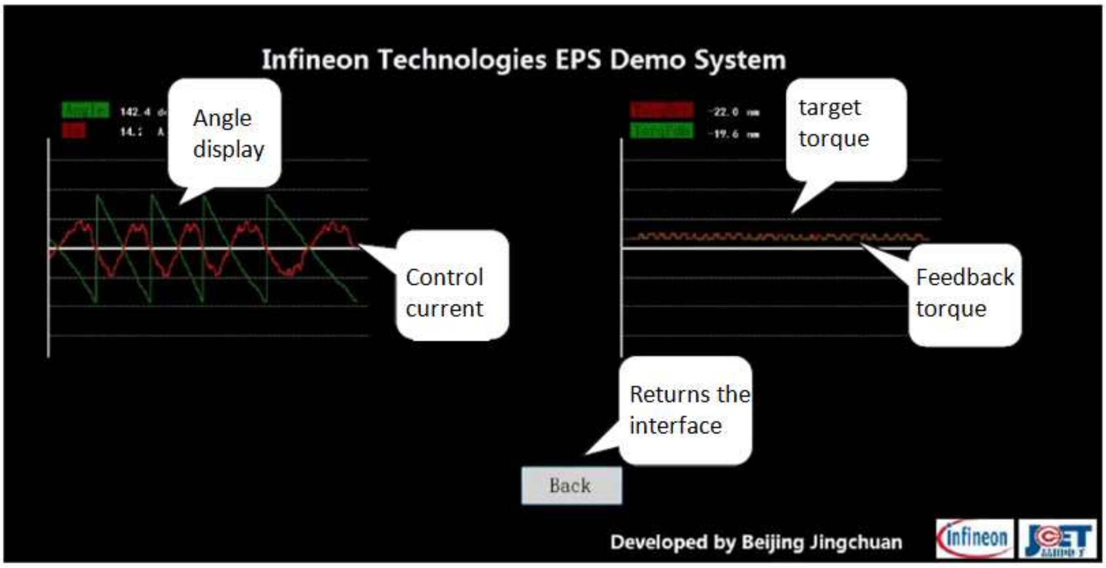


Figure 5.2 shows the interface